9. RETENTION FRACTIONS FOR MULTIPLE AND CONTINUOUS INTAKES OF SELECTED NUCLIDES

Single intake tabulations may also be applied to prolonged or continuous intake satisfactorily. In practice, a worker may receive repeated exposures to the same radionuclide during a controlled period. If these intakes are separated by not less than three or four effective half-lifes, each one can be treated as a single intake, evaluated with the help of these tabulations, and the individual exposures added together to estimate total dose. If they are not so separated, they should be treated as a prolonged or continuous intake. Although there are special methods (Sk81) to estimate prolonged and continuous intake, it may be done by using the relevant Intake Retention Fraction for single intake which is given in this manual. Estimates of intake obtained by either method will differ by only a few percent.

A model adopted by Muller et al. (Mu66) projects a total intake of A μCi evenly distributed over T days, that is, an average of A/T μci per day. This is a reasonable model for irregularly repeated intakes of different magnitudes. As long as the intakes are not asymmetrically distributed in size and time, then the IRFs which are derived by using Muller's approximation will be reasonably accurate.

The expression which describes the expected content $\langle q(t) \rangle$ of a radionuclide for constant continuous intake is given by:

$$\langle q(t) \rangle = \frac{A}{T} \int_{o}^{t} r(u)\, du \qquad \text{for } t<T \qquad \text{(B.9.1)}$$

$$\langle q(t) \rangle = \frac{A}{T} \int_{t-T}^{t} r(u)\, du \qquad \text{for } t \geq T \qquad \text{(B.9.2)}$$

where:

- u = variable time between integration limits,
- $r(u)$ = intake retention fraction in compartment or whole body for a single intake of radionuclide, which can be found in this manual,
- $q(t)$ = amount or activity of radionuclide in question in the compartment or whole body at time t post the onset of intake,
- A = total amount of activity intake during the period of T.

The equations B.9.1 and B.9.2 are suitable for estimating the intake based on the in vitro measurements by substituting the fraction of intake for 24-hour excretion or accumulated excretion in place of the retention fraction for compartments or the whole body.

The single intake retention functions r(u) in this report all can be expressed as a sum of exponential terms with constant coefficients (Sk83):

$$r(u) = \sum_{j=1}^{n} C_j \; e^{-k_j t},$$

where $k_j = K_j + \lambda$ = total removal rate constant for compartment j. When this expression for r(u) is substituted into the expression on the right hand side of equations B.9.1 and B.9.2, the expected contents $\langle q(t) \rangle$ are respectively expressed:

$$\langle q(t) \rangle = \frac{A}{T} \sum_{j=1}^{n} C_j \; \frac{(1-e^{-k_j t})}{k_j}, \qquad \text{(B.9.3)}$$

for $t<T$, and

$$\langle q(t) \rangle = \frac{A}{T} \sum_{j=1}^{n} C_j \; \frac{(1-e^{-k_j T})}{k_j} \; e^{-k_j (t-T)}, \qquad \text{(B.9.4)}$$

for $t \geq T$.

These expressions can be used to define a continuous intake retention function p(t), which gives the fraction of the total intake expected to be present at times t post the onset of continuous intake: $p(t) = \langle q(t) \rangle / A$ or $p(t) = \langle q(t) \rangle / (A/T)t$, which shows that the continuous intake retention function p(t) can be obtained from the single intake retention functon by simply replacing $e^{-k_j t}$ in equation 2.5.1 by:

$$\frac{(1-e^{-k_j T})}{k_j T} \; e^{-k_j (t-T)}, \quad \text{for } t \geq T,$$

or by:

$$\frac{(1-e^{-k_j t})}{k_j t}, \quad \text{for } t<T.$$

In the later case $p(t) = \langle q(t) \rangle / (At/T)$, the fraction of the total intake present at the end of the intake interval t.

Except for the case where $t<T$, these same replacement functions are applicable to converting a single intake type incremental excreta function to a continuous intake type. Replace $e^{-k_j t}$ in the single intake incremental excreta function by:

$$\frac{(1-e^{-k_j T})}{k_j T} \; e^{-k_j T}, \quad \text{for } t \geq T+\Delta t,$$

or replace $e^{-k_j t}$ in the single intake accumulated excreta function by:

$$\frac{-e^{-\lambda \Delta t} \; (1-e^{-k_j T}) \; e^{-k_j (t-\Delta t-T)} \; (1-e^{-(k_j-\lambda)\Delta t})}{k_j T},$$

for $t \geq T+\Delta t$.

The integration of the equations above also can be obtained by numerical methods as follows:

$$\int_a^b f(x)dx = h \left[\frac{f(X_o) + f(X_n)}{2} + f(X_1) + \ldots f(X_{n-1})\right] \qquad (B.9.5)$$

where:

$$h = \frac{b-a}{n}, \quad X_o = a, \quad X_n = b, \quad X_i = a + ih,$$

i = the ith increment and
n = the number of increments.

As long as one divides the integration region a to b into appropriate increments, the accuracy of the result is good.

IRF values can be obtained for any time t of interest by interpolating the data in the manual. The best method is by plotting as done in Figure B.9.1. For example, whole-body counting for person A and urine sampling for person B were performed on March 1, 1982, and they showed both workers were internally contaminated with cobalt-60. They worked with cobalt-60 from January 5, 1981 to December 25, 1981. The mode of exposure was assumed to be constant continuous inhalation.

The whole-body counting result was 1.2 E+04 Bq (0.33 μCi), and the urine result was 3.4 E+01 Bq (0.91 nci). In this case, the intake period T is 350 days, and the time of interest post onset of intake is 420 days. The integration region was divided into seven intervals and each is 50 days. Estimated constant continuous IRF values were as follows:

Table B.9.1. IRFs and Time Post Single Intake

Time Post Intake(Days)	IRF (Total Body)	IRF 24-Hour Urine
70	7.87×10^{-2}	2.17×10^{-4}
120	4.60×10^{-2}	1.30×10^{-4}
170	3.05×10^{-2}	8.20×10^{-5}
220	2.15×10^{-2}	5.25×10^{-5}
270	1.62×10^{-2}	3.40×10^{-5}
320	1.33×10^{-2}	2.22×10^{-5}
370	1.13×10^{-2}	1.40×10^{-5}
420	1.00×10^{-2}	1.00×10^{-5}

thus, for the total body,

$$\int_{70}^{420} r(\breve{u})\, du = 50 \times \left[\frac{7.87 + 1.00}{2} + 4.60 + 3.05 + 2.15 + 1.62 + 1.33 + 1.13\right] \times 10^{-2}$$

$$= 9.16,$$

and for 24-hour urine

$$\int_{70}^{420} r(u)\, du = 50 \times \left[\frac{21.7 + 1.00}{2} + 13.0 + 8.20 + 5.25 + 3.40 + 2.22 + 1.40\right] \times 10^{-5}$$

$$= 2.24 \times 10^{-2}.$$

Substituting the whole-body counting data into equation B.9.2 yields:

$$1.2\ \text{E04 Bq} = \frac{A}{T}\int_{70}^{420} r(u)\, du = \frac{A}{350}\,(9.16)$$

Thus, the intake A is 4.7 E+05 Bq (12.6 μCi).

Substituting the one-day urine data into equation B.9.2. yields:

$$3.4\ \text{E01 Bq} = \frac{A}{T}\int_{70}^{420} r(\breve{u})\, du = \frac{A}{350}\,(2.24 \times 10^{-2})$$

Thus, the intake is 5.3 E+05 Bq (14.2 μCi).

If exact analytical solutions are used for this example rather than numerical integration methods, the IRF for the total body is 2.58 E-02 and the IRF for a 24-hour urinary sample is 6.19 E-05. Thus, for a 350 day interval of continuous intake followed by a 70 day interval of no exposure, the intake based on whole-body counting is 4.7 E+05 Bq (12.8 μCi) and for a urinary sample measurement, the intake is estimated to be 5.4 E+05 Bq (14.7 μCi). These values compare closely to values obtained by using the numerical integration technique given above.

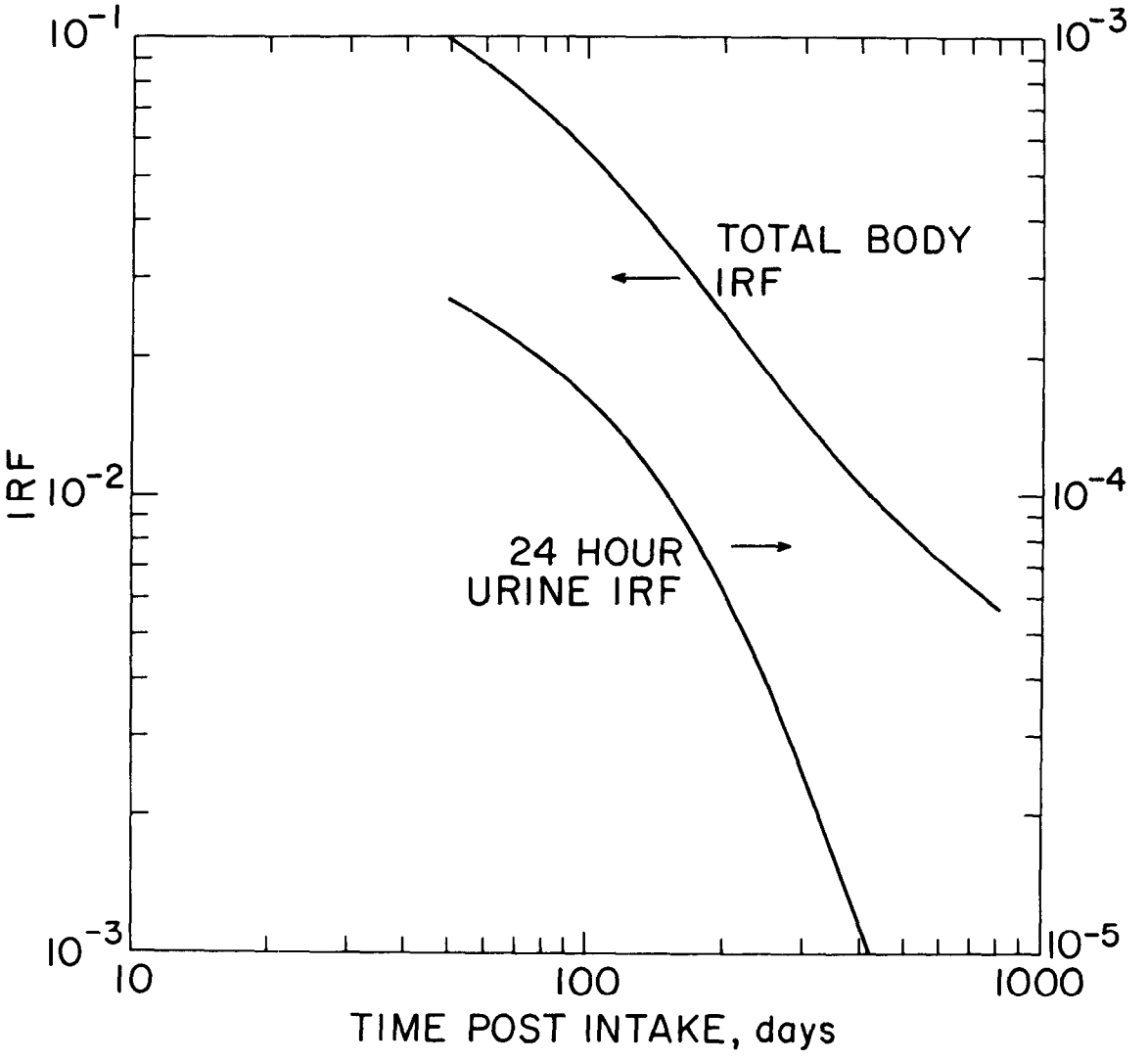

FIGURE B.9.1 Total Body and 24-hour Urine IRF for Co-60 Class W aerosols.